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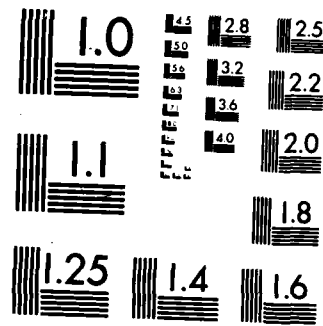
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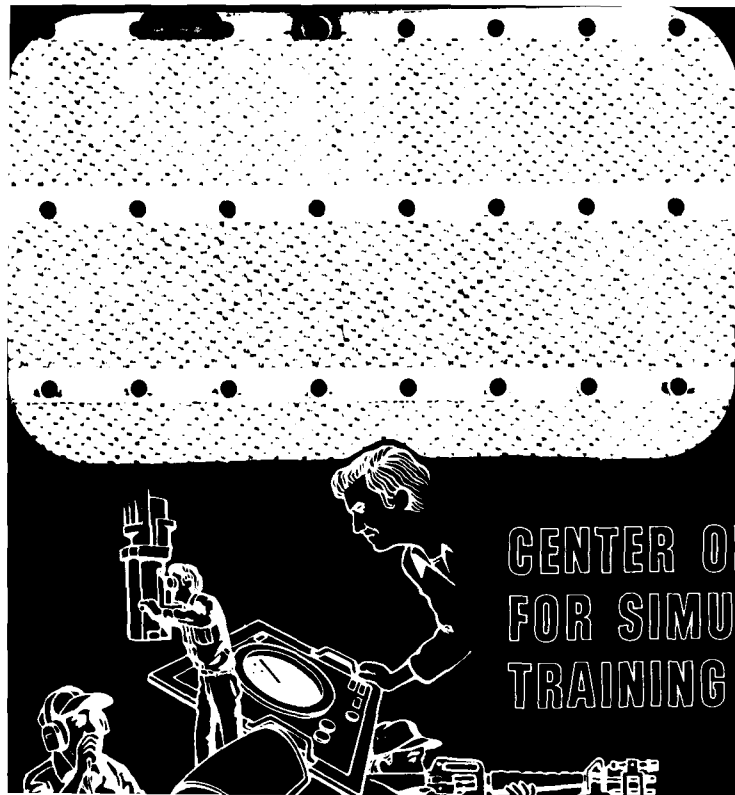
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VEHICULAR SIMULATOR-INDUCED SICKNESS,
VOLUME II: A SELECTED ANNOTATED
BIBLIOGRAPHY

by

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IEOR Technical Report No. 8502

FINAL REPORT AUGUST 1986

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SECURITY CLASSIFICATION OF THIS PAGE

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REPORT DOCUMENTATION PAGE

1. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release: Unlimited Distribution	
7b. DECLASSIFICATION / DOWNGRADING SCHEDULE			
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 1K IEOR/V8502		5. MONITORING ORGANIZATION REPORT NUMBER(S) NTSC-TR86-011	
6a. NAME OF PERFORMING ORGANIZATION Virginia Polytechnical Institute and State University	6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION Naval Training Systems Center	
6c. ADDRESS (City, State, and Zip Code) Human Factors Laboratory Blacksburg, VA 24061		7b. ADDRESS (City, State, and Zip Code) Code 711, Human Factors Division Orlando, FL 32813-7100	
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Office of Naval Research	8b. OFFICE SYMBOL (if applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-84-K0226	
8c. ADDRESS (City, State and Zip Code) Arlington, VA 22217		10. SOURCE OF FUNDING NUMBERS	
		PROGRAM ELEMENT NO.	PROJECT NO.
		TASK NO.	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Vehicular Simulator-Induced Sickness, Volume II: A Selected Annotated Bibliography			
12. PERSONAL AUTHOR(S) Casali, John G. and Roesch, J. Richard			
13a. TYPE OF REPORT FINAL	13b. TIME COVERED FROM 8509 TO 8608	14. DATE OF REPORT (Year, Month, Day) 86/08/31	15. PAGE COUNT 39
16. SUPPLEMENTARY NOTATION (10)			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	
05	05		
05	08		
		Simulators, Flight Simulators, Simulation Sickness, Simulator Induced Syndrome.	
19. ABSTRACT (Continue on reverse if necessary and identify by block number)			
<p>A serious problem associated with training and research applications of both ^{driving} flight and ^{driving} simulators is the provocation of illness symptoms and aftereffects in human subjects. In spite of its frequency and severity, human factors research attention to the problem of simulator sickness has been somewhat scant. However, documentation of a number of instances of simulator-induced sickness appears in journal articles, technical reports, and memoranda. Several other publications have specifically addressed the symptomatology and/or the etiology of the problem, while a few papers have described laboratory or field studies. This report includes bibliographic listings and abstracts for those references which have direct mention of or close association with, simulator sickness. The collection is limited to references dealing specifically with simulator sickness and does not attempt to represent the plethora of associated articles on motion sickness and human perception. The majority of the bibliography is comprised of incidence reports, field surveys, technical memoranda on specific simulators, reports on countermeasures, and research studies on simulator design aspects, procedural and operational aspects, and subject individual differences such as experience level and perceptual</p>			
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL LCDR MICHAEL G. LILIENTHAL	22b. TELEPHONE (Include Area Code) (305) 646-5130	22c. OFFICE SYMBOL 711	

19. ABSTRACT (cont):

style. It is intended to provide the researcher or simulator user with an up-to-date source of background documents representing the state of knowledge on simulator sickness.

SUMMARY

A serious problem associated with training and research applications of both flight and driving simulators is the provocation of illness symptoms and aftereffects in human subjects. In spite of its frequency and severity, human factors research attention to the problem of simulator sickness has been somewhat scant. However, documentation of a number of instances of simulator-induced sickness appears in journal articles, technical reports, and memoranda. Several other publications have specifically addressed the symptomatology and/or the etiology of the problem, while a few papers have described laboratory or field studies on simulator sickness. This report includes bibliographic listings and abstracts for those references which have direct mention of, or close association with, simulator sickness. The collection is limited to references dealing specifically with simulator sickness and does not attempt to represent the plethora of associated articles on motion sickness and human perception. The majority of the bibliography is comprised of incidence reports, field surveys, technical memoranda on specific simulators, reports on countermeasures, and research studies on simulator design aspects, procedural and operational aspects, and subject individual differences such as experience level and perceptual style. It is intended to provide the researcher or simulator user with an up-to-date source of background documents representing the state of knowledge on simulator sickness.

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ACKNOWLEDGEMENTS

This report describes work conducted at Virginia Polytechnic Institute and State University for the Office of Naval Research, Arlington, Virginia, who provided funds through ONR Grant Number N00014-84-K0226. Special thanks are due Mr. Donald Woodward, who served as scientific officer, and LCDR Michael Lilienthal of the Naval Training Systems Center (NTSC) who worked closely with the research team on all phases of the project as grant monitor. The authors are indebted to LCDR Lawrence H. Frank, formerly of NTSC and now at Virginia Tech, who provided the initial impetus for the project and made many helpful suggestions throughout, and to Dr. Robert S. Kennedy of Essex Corporation, Dr. Michael E. McCauley of Monterey Technologies, Inc., and Mr. Joseph A. Puig of NTSC for their pioneering efforts in motion sickness and simulator sickness.

A preliminary version of a Naval Training Systems Center report entitled, "Simulator Sickness: Reaction to a Transformed Perceptual World--II. Sourcebook and Suggested Readings," by R. S. Kennedy, L. H. Frank, and M. E. McCauley, was helpful in generating several sources for this bibliography. Also, an earlier literature review performed by J. G. Casali for a master's thesis entitled, "A Multivariate Investigation of the Effects of Various Design Alternatives on Driving Simulator Discomfort," yielded many references cited herein.

Opinions or conclusions contained in this report are those of the authors and do not necessarily reflect the view or endorsement of the Navy Department.

INTRODUCTION

Problem

The problem of vehicular simulator-induced sickness has serious implications for training and research in that it can compromise training objectives, result in negative transfer of training, invalidate research results, and potentially increase risk in subsequent operation of the actual vehicle. Many questions regarding both the etiology and symptomatology of simulator-induced sickness warrant research attention, as simulator design and operating procedures must be improved to ameliorate the problem. While there has been relatively little empirical research aimed at simulator sickness, since 1957 a number of documents addressing the sickness problem have surfaced. It is these documents which comprise this collection of bibliographic entries and associated abstracts.

Approach

A thorough library literature search, including the National Technical Information Service and Psychological Abstracts files was conducted, as was a search of bibliographic reference lists included in pertinent journal articles and technical reports. Only selected references which appeared to be readily available to the public, either in reprint form or from the respective authors, are included. Again, the entries were selected on the basis that they were specific to simulator sickness.

The resulting annotated bibliography includes selected references from numerous technical reports, journal articles, conference proceedings, technical memoranda, and texts. Specifically, the material includes incidence reports of simulator-induced sickness, correspondence regarding particular simulator problems, field survey results, reports on countermeasures to

alleviate sickness, and research efforts concerning experimentation on simulator design aspects, operating procedures, and intra- and inter-individual differences influencing susceptibility.

Wherever possible, abstracts written by the author of each reference are included. In some cases a formal abstract could be not obtained. For these, a brief summary of those aspects of the reference most germane to simulator sickness was written by the compilers of this bibliography.

Application

This annotated bibliography constitutes a source of background documents for summarizing the state of current knowledge and for planning future research on simulator-induced sickness. The listings should prove useful to researchers, training personnel, simulator designers, and simulation practitioners who are confronted with the potential of subject or trainee sickness.

Recommendation

Periodically, this bibliography will require updating to include future documents dealing with simulator-induced sickness.

AGARD. (1980, December). Fidelity of simulation for pilot training (AGARD Advisory Report No. 159). Neuilly sur Seine, France. (Printed by Technical Editing and Reproduction, Ltd., Harford House, 7-9 Charlotte, St., London).

Technology is allowing the simulation of increasingly complex flight situations with more and more fidelity. High fidelity generally implies high cost, but high fidelity is not always necessary to obtain satisfactory training. This report addresses the subject of fidelity of simulation for pilot training and provides background to specialists in the multiple disciplines involved. Topics presented in detail are: the training psychologist's views on fidelity of simulation required to train, and methods of assessing this fidelity; the physiologist's survey of pilot cuing mechanisms, in particular those provided by motion or visually-induced motion sensations; and the simulator technologist's assessment of existing motion, visual and aircraft mathematical model technology and the characteristics which could be expected to provide high perceptual fidelity. In each of these disciplines, deficiencies are identified in the current ability to relate simulator fidelity to the needs for pilot training and recommendations are made for structuring future research efforts.

AGARD. (1979, September). Dynamic characteristics of flight simulator motion systems (AGARD Advisory Report No. 144) Neuilly sur Seine, France. (Printed by Technical Editing and Reproduction, Ltd., Harford House, 7-9 Charlotte, St., London).

In the last five years, there has been a sharp rise in the number of simulation facilities employing multiple degree-of-freedom motion systems; however, until recently no substantive attempts have been made to measure the performance of these systems. Those measurements that have been made and published have not been made in a uniform way, so that it is difficult to compare different systems. While data on the gross excursions, velocities and accelerations of these systems have been generally available in the literature, dynamic response, noise and other imperfections were usually neither carefully measured nor was information on them widely distributed. This Advisory Report specifies a uniform method of measuring and reporting motion performance characteristics, developed by a Working Group of the Flight Mechanics Panel of AGARD. Such a uniform method, in addition to aiding system comparison, can assist in system diagnosis and might be used in writing performance specifications. The definitive characteristics selected for system description are excursion limits, describing function, linearity and acceleration noise, hysteresis, and dynamic threshold. Definitions and methods of measurement and display are given and illustrated by measurements on particular motion systems.

Alexander, R. A., and Barrett, G. V. (1975). Relationship between perceptual style and responses to visual motion under active and passive viewing conditions. Journal of Applied Psychology, 60 (4), 507-512.

Twenty extreme field-dependent and 20 extreme field-independent males viewed an 8-min. segment of film showing high-speed automobile travel. Half watched the film passively, and half watched while actively initiating leg movements in response to the car's expected turning direction. Skin conductance level was monitored from two nonpalmar sites, and the subjects reported the extent to which specific sensations were experienced. It was found that in the passive viewing condition, field-independent subjects showed greater increases in skin conductance levels than field-dependent subjects, but in the active viewing condition, both types of individuals showed similar increases. Electrodermal activity change was found to be associated with reported sensations of general discomfort and illusory motion.

Allen, R. W., Klein, R. H. and Ziedman, K. (1979, January). Automobile research simulators - a review and new approaches (STI Paper No. 38). Hawthorne, CA: Systems Technology, Inc. (Paper presented at the 58th Annual Meeting of the Transportation Research Board, Washington, D.C.)

As evidenced by an increasing number of successful research driving simulator systems and applications over the last few years, driving simulation technology is rapidly expanding. This paper reviews current driving simulator state of the art, and presents examples of two simulators with advanced visual display capabilities. Finally, anticipated future developments in simulation technology related to research, driver training, and licensing applications are discussed. Mention is made of a new kind of simulator design factors, some of which may have bearing on simulator sickness.

Barrett, G. V., Kobayashi, M., and Fox, B. H. (1968). Feasibility of studying driver reaction to sudden pedestrian emergencies in an automobile simulator. Human Factors, 10, 19-26.

An experiment was conducted to determine the feasibility of studying driver reaction to sudden pedestrian emergencies in an unprogrammed automobile simulator. A random sample of 11 male subjects followed an identical procedure. Each subject went through a speed estimation study which was designed so that the subject would drive past the shed containing the pedestrian (dummy) 11 times. This was done so that the emergency of the pedestrian would be completely unsuspected. The subject drove in the right lane of the road at approximately 25 mph. When the subject was 82.5 ft. from the shed containing the pedestrian, the microswitch was tripped which released the dummy into the center of the road at a controlled rate. During the study a continuous record of speed, time, brake position, steering wheel position, lateral position of vehicle, longitudinal position of vehicle, and position of pedestrian was recorded. All of the subjects tried to avoid the pedestrian, either by brake application or by a steering change. Since this was a feasibility study with a small sample, no conclusions were drawn beyond the data, but the possibility of productive research in this area using simulation techniques seems to have been opened. A number of subjects exhibited symptoms indicative of acute simulator sickness.

Barrett, G. V. and Nelson, D. D. (1965, December). Human factors evaluation of a driving simulator -- summary of human factors evaluation, 15, (Goodyear Engineering Report No. 12400). Goodyear Aerospace Corporation.

An extensive human factors evaluation was performed on a fixed-base Goodyear Aerospace driving simulator with a large-screen projection TV display. Of 25 subjects who began the evaluation program, 11 became too sick to finish and 2 reached full emesis. The authors noted the lack of physical motion as a potential etiological factor in the production of sickness.

Barrett, G. V. and Nelson, D. D. (1966, March). Human factors evaluation of a driving simulator -- summary of virtual image display studies, 20, (Goodyear Engineering Report No. 12400). Goodyear Aerospace Corporation.

In this report, a fixed-base driving simulator evaluation is described. The device incorporated an infinity optics, virtual image CRT display. In the evaluation studies, 14 of 25 subjects could not finish the simulated driving task due to sickness. Discussion of potential sickness causes is included.

Barrett, G. V. and Thornton, C. L. (1968a). Relationship between perceptual style and driver reaction to an emergency situation. Journal of Applied Psychology, 52 (2), 169-176.

Previous investigators have found low relationship between human characteristics and accident behavior. The possibility was raised that these findings might be due to a number of factors including indiscriminate grouping of accidents and choice of predictors which have no logical relationship to accident behavior. In the present study 20 drivers were subjected to a controlled emergency situation in an unprogrammed automobile simulator, where a pedestrian (dummy) emerged from a shed into the path of the vehicle. Subsequent measurements of individual perceptual style, using the Rod and Frame Test (RFT), were correlated with effectiveness of reaction to the emergency situation. Series 3 of the RFT correlated 0.67 with reaction time, 0.75 with deceleration rate, and 0.50 with a hit-miss criterion. Individual differences in perceptual style and simulator discomfort resulted in shrunken multiple correlations of 0.89-0.95 depending on the data transformations. The extrapolation of the results to real-world accident behavior has implications especially with regard to age, sex, and use of alcohol by drivers.

Barrett, G. V. and Thornton, C. L. (1968b). Relationship between perceptual style and simulator sickness. Journal of Applied Psychology, 52 (4), 304-308.

Simulator sickness was hypothesized to be caused by the conflict between the visual presentation of apparent motion and the lack of any corresponding body sensation of motion. The hypothesis was tested by correlating individual differences in scores on the Rod and Frame Test (RFT; which measures accuracy of adjustment of a rod to true vertical under conditions of visual-kinesthetic conflict) and degree of simulator sickness. The data for Series 3 of the RFT and the indexes of sickness were best represented by hyperbolic functions yielding correlations of 0.40-0.52. Implications for simulation technology and for a general conflict of cue theory are discussed with emphasis on supporting evidence from several areas of investigation.

Barrett, G. V., Thornton, C. L., and Cabe, P. A. (1969). Relation between embedded figures test performance and simulator behavior. Journal of Applied Psychology, 53 (3), 253-254.

Relationships previously found with reaction to an emergency situation and simulator sickness compared to the Rod and Frame Test (RFT) measure of perceptual style were extended using a second perceptual style measure, an embedded figures test (EFT). The RFT was significantly related to emergency behavior and to simulator sickness. The EFT was significantly related to emergency behavior but not to the simulator sickness. Implications for the use of both tests in the prediction of driving behavior are discussed.

Barrett, G. V., Thornton, C. L., and Cabe, P. A. (1970). Cue conflict related to perceptual style. Journal of Applied Psychology, 54 (3), 258-264.

Four hypotheses based on past research were tested in this investigation. First, it was hypothesized that field-independent individuals would experience more discomfort in a cue conflict situation. Just the opposite occurred; field-dependent individuals experienced the most discomfort. Second, it was hypothesized that those at the augments end of the continuum on the Kinesthetic Figural Aftereffects Test (KFAET) would experience more discomfort in a conflict situation. Results showed that there was no relationship between the KFAET and discomfort. Third, it was hypothesized that the KFAET would be related to past history of motion sickness. No relationship was obtained. The fourth hypothesis was that the past history of motion sickness would relate to discomfort in the conflict situation. This hypothesis was also disconfirmed as there was no relationship found between prior history of motion sickness and discomfort in the conflict device.

Beinke, R. E. and Williams, J. K. (1968, July). Driving simulator. Paper presented at the General Motors Corporation Automotive Safety Seminar, Milford, Michigan.

This paper describes an early moving-base driving simulator at the General Motors Technical Center which has since been dismantled. It was reported to produce vertigo (see Jex and Ringland, 1973) when motion was deactivated. The device was developed for research purposes and utilized a wide screen motion picture display and cab tilt for simulation of lateral and longitudinal acceleration.

Breda, W. M., Kirkpatrick, M., and Shaffer, C. L. (1972). A study of route guidance techniques (Report No. DOT-FH-11-7708). Columbus, OH: North American Rockwell Corporation.

This report describes research conducted on route guidance techniques in driving, using a terrain-board TV projection display simulator with heave, pitch, and roll motions. Acute illness was experienced by several subject drivers who had difficulty in continuing the driving task. The simulator was converted from a flight simulator and has since been dismantled.

Browder, G. B., and Butrimas, S. K. (1981). Visual technology research simulator visual and motion system dynamics. (Technical Report: NAVTRAEQUIPCEN IH-326). Orlando, FL: Naval Training Equipment Center.

Simulator system time lags and transport delays can be critical factors in achieving a successful modern trainer. This document presents the results of detailed measurements made on the Navy's Visual Technology Research Simulator (VTRS/CTOL). These measurements determined "end-to-end" dynamic lags, with aircraft control stick as the input stimulus and visual/motion hardware response as the output. Major subsystems of the VTRS/CTOL include a T-2C aircraft cockpit, pneumatic G-seat, six degree of freedom motion base, wide angle dome display with a servo-controlled projection system driven with either CIG or closed circuit model board TV. Dynamic performance data shows phasing between the motion and visual systems for CIG and model board simulation. This study concludes that the VTRS/CTOL simulator throughput lags are less than 150 milliseconds which is generally accepted as satisfactory for simulation.

Casali, J. G. (1979). A multivariate investigation of the effects of various design alternatives on driving simulator discomfort. Master's thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

A thorough overview of existing driving simulators was compiled, including information on the tendency of each simulator to induce subject illness, if any. On the basis of overview and related research on motion sickness, hypotheses concerning several potential influences of driving simulator discomfort were formulated. The effects of three independent variables on eight measures of driving simulator discomfort were investigated using a high-fidelity, moving-base driving simulator. The between-subjects simulator variables were: (a) simulation of lateral acceleration (LAT) -- by lateral translation (normal method) versus by angular rotation, (b) presence or absence of delay in the visual and motion feedback dynamics (DEL) -- nondelayed (normal) versus delayed, and (c) simulator cab (CAB) -- open (normal) versus enclosed. Sixty-four subjects participated in the study; eight subjects were assigned to each of eight simulator conditions on the basis of pretest scores on a test of field independence-dependence. Subjects in each condition constituted a cross-sectional representation of test scores from a quartile ranking of all scores. After subjects drove the simulator, a multivariate analysis of variance was performed on the data and resulted in significance for each main effect and one interactional effect (LAT by DEL). Subsequent analyses demonstrated that the dependent measures of pallor, skin resistance, respiration rate, yaw deviation, and steering reversals were each reliably sensitive to changes in at least one of the simulator variables. However, no subjects exhibited high levels of sickness, suggesting that other simulator factors, or factors of larger magnitude, may be responsible for simulator sickness.

Casali, J. G. (1981). Evaluation of various design alternatives influencing discomfort in a driving simulator. In J. Moraal and K. F. Kraiss (Eds.), Manned systems design, methods, equipment and applications (pp. 449-463). New York: Plenum.

Several important conclusions concerning simulator design can be made on the basis of the empirical data and literature review results reported. First, it is apparent that physical motion cues should be simulated with accurate movements in the same physical axis as in the full-scale vehicle. This is certainly feasible, using appropriately "washed-out" motion cues and reasonable excursion distances, and by taking advantage of the fact that the operator does perceive accelerations and decelerations but does not perceive them at low levels. Also, constant velocities are not perceived. The alternative techniques of simulating translational accelerations with rotational motions may reduce motion-base costs and conserve laboratory space, but these methods tend to be problematic in terms of both sickness inducement and undesirable handling. The controlling systems for the simulator response variables should be free of any computational delays or servo lags to ensure that the manual control inputs are coordinated with the visual and physical motion feedback cues. If not, subject uneasiness may result and vehicle controllability may degrade. Delayed feedback in response to steering inputs burdens the driving subject with the task of introducing compensating lead to control the vehicle. The increased workload and constant attentional demand placed on the subject may heighten the stress level, further contributing to malaise. On both fixed-base and moving-base simulators, the necessity of a box-type cab is questionable. As previously discussed, the presence of an enclosure over the driver platform was sufficient for significantly increased forehead perspiration and respiration rate. Furthermore, in most cases it is doubtful that a windowless, box-type cab enhances the fidelity of a driving simulator.

Casali, J. G. and Wierwille, W. W. (1980). The effects of various design alternatives on moving-base driving simulator discomfort. Human Factors, 22 (6), 741-756.

The effects of three independent variables on eight measures of driving simulator discomfort were investigated using a high-fidelity, moving-base driving simulator. The between-subjects simulator variables were: (a) simulation of lateral acceleration (LAT)--by lateral translation (standard method) versus by angular rotation; (b) presence or absence of delay in the visual and motion systems (DEL)--nondelayed (normal) versus delayed; and (c) simulator platform (CAB)--open (normal) versus enclosed. Sixty-four subjects were divided into eight groups, each group having equally distributed scores on a test of field independence-dependence. Each group was then assigned to one of the eight simulator conditions. After subjects drove the simulator, a multivariate analysis of variance was performed on the data and resulted in significance for each main effect and the LAT x DEL interaction. Subsequent analyses demonstrated that dependent measures of pallor, skin resistance, respiration rate, yaw deviation, and steering reversals were each reliably sensitive to at least one of the simulator independent variables. It is concluded that future simulator designs should avoid: rotation of the platform to simulate translation, delays in the system dynamics, and the complete enclosure of subjects.

Casali, J. G. and Frank, L. H. (1986, January) Perceptual distortion and its consequences in vehicular simulation: An overview of the simulator sickness problem. Paper presented at the Transportation Research Board Meeting, Washington, D.C. (In press for the Transportation Research Record.)

Simulator-induced sickness is a serious problem which can afflict the users of certain unprogrammed vehicular simulators, including aircraft and driving devices. Operators and passengers in training and research simulators have experienced symptoms akin to those of motion sickness both during and following a simulator experience. In some cases, even several hours post-exposure, aftereffects or flashbacks to the simulation environment may surface, creating sudden disorientation in the individual. The simulator-sickness syndrome appears to be severe and frequent enough that it affects the utility of simulation and may create safety hazards for users. It has, therefore, received considerable attention by the human engineering community of late. This paper provides background information on the sickness problem, a discussion of its parameters, implications in training and research applications, and its theoretical underpinnings. A brief, tabularized literature review specific to simulator sickness is also included. All available articles, reports, technical memoranda, and papers directly dealing with the problem of operator discomfort in vehicular simulators were obtained and selectively reviewed. Finally, a number of operational countermeasures for curtailing the problem are presented.

Casali, J. G. and Wierwille, W. W. (1986, January). Potential design etiological factors of simulator sickness and a research simulator specification. Paper presented at the Transportation Research Board Meeting, Washington, D.C. (In press for the Transportation Research Record.

This paper addresses the problem of vehicular simulator-induced sickness from the standpoint of simulator design etiological factors. A brief discussion of engineering design characteristics which exhibit potential for contributing to simulator sickness is presented. This discussion draws from studies performed on simulators to date along with other pertinent perceptual distortion literature and documentation of specific simulator problems. Potential etiological factors covered include control loop lags and delays, control loading and damping, dynamic inaccuracies, fixed-base/motion-base issues, illusory motion techniques, anomalous motion cues, motion enhancement devices, visual generation systems, field-of-view, scene detail and visual motion, dynamic imaging problems, display distortions, and cockpit environment factors. Based on these potential etiological factors, requirements for a generic simulator research facility to investigate simulator engineering design influences on sickness are proposed.

Casto, J. H. (1982, September). Simulator sickness. Weekly Summary of Aircraft Mishaps (U.S. Naval Safety Center), No. 38-82, 1.

Causes, symptoms and the effects of simulator sickness in the F-4/F-14, 2E6 Air Combat Maneuvering simulator are discussed. It is suggested that no pilot be scheduled to fly an aircraft within 12 hours of the first exposure to the simulator. Maximum training durations for the 2E6 simulator are also suggested.

Cohen, E. (1970). Is motion needed in flight simulators for training? Human Factors, 12 (1), 75-79.

Although flight training curricula demand that pilots learn to disregard bodily sensations of motion, aircraft motion can be an important source of information to pilots, and sometimes can also degrade pilot performance. Considerable evidence is adduced that motion in flight simulators produces significant training benefits, but there is a scarcity of data on the consequences of different degrees or methods of motion simulation. To produce the sensation of miles of aircraft motion with a few feet of simulator motion requires consideration of various aspects of human sensitivity to motion. Some of the complications in obtaining motion-threshold data are discussed, and two illustrations of the utilization of these data in optimizing motion simulation are given.

COMPATWINGSLANT, (1980, April). 2F87(F) serial no. 5 FE and co-pilot display. U.S. Navy message from COMPATWINGSLANT, Brunswick, ME, to CNO, Washington, D.C.

This message notes the P-3C 2F87(F) visual display deficiencies - the lack of a center visual display for the flight engineer and the lack of a forward quarter window display for the co-pilot. It is stated that the presence of these displays would improve the quality of training and reduce the risk of disorientation, sickness and fatigue.

Coward, R. E., Kellogg, R. S. and Castore, C. H. (1979, December). Which way is up? SAACing the dizzies. Tac Attack, 12-14.

This short article presents a discussion of simulator sickness and aftereffects, their possible causes, and ramifications in the Air Force simulator for air-to-air combat (SAAC). The emphasis is on simulator-induced "orientation disturbances" and the maneuvers that elicit them.

Crampton, G. H., and Young, F. A. (1953). The differential effect of a rotary visual field on susceptibles and nonsusceptibles to motion sickness. Journal of Comparative and Physiological Psychology, 46, 451-453.

Two groups of subjects, one susceptible and the other not susceptible to motion sickness, were subjected to a rotating room situation in which they remained stationary. The resulting nausea symptoms were categorized on an arbitrary four-point scale. The results indicate that individuals susceptible to motion sickness are also susceptible to nausea in a rotary visual field situation, and, conversely, nonsusceptibles are resistant. It is concluded that some of the individual differences in regard to nausea found in previous studies utilizing rotary visual fields may be related to the motion sickness susceptibility of the subjects.

Crane, D. F. (1983, June). Compensation for time delay in flight simulator visual-display systems (AIAA-83-1080). Paper presented at the AIAA Flight Simulation Technologies Conference, Niagara Falls, NY.

A piloted aircraft can be viewed as a closed-loop, man-machine control system. When a simulator pilot is performing a precision maneuver, a delay in the visual display of aircraft response to pilot-control input decreased the stability of the pilot-aircraft system. The less stable system is more difficult to control precisely. Pilot dynamic response and performance change as the pilot attempts to compensate for the decrease in system stability, and these changes bias the simulation results by influencing the pilot's rating of the handling qualities of the simulated aircraft. Delay compensation, designed to restore pilot-aircraft system stability, was evaluated in several studies which are reported here. The studies range from single-axis, tracking-task experiments (with sufficient subjects and trials to establish statistical significance of the results) to a brief evaluation of compensation of a computer-generated-imagery (CGI) visual display system in a full six-degree-of-freedom simulation. The compensation was effective--improvements in pilot performance and workload or aircraft handling-qualities rating (HQR) were observed. Results from recent aircraft handling-qualities research literature which support the compensation design approach are also reviewed.

Crosby, T. N., and Kennedy, R. S. (1982, May). Postural disequilibrium and simulator sickness following flights in a P3-C operational flight trainer. Paper presented at the 53rd Annual Scientific Meeting of the Aerospace Medical Association, Bal Harbor, FL.

Variable amounts of standing and walking unsteadiness have been reported following training missions in the Navy's ground-based P3-C operational flight trainer (2F87). This disequilibrium is accompanied by other symptoms related to vestibular upset (dizziness, vertigo, stomach awareness, headache). Reviews of previously published reports of Air Force and Navy simulator sickness studies show that while leans, unsteadiness, ataxia and incoordination had been reported before, this aspect of simulator sickness has not previously been emphasized. It is believed that these conditions can reduce the effectiveness of training, and perhaps more importantly, pose a threat to aircrew safety in the event of air or motor vehicle operations during the period of the post-simulator exposure.

FITRON ONE TWO FOUR, (1981, October). F-14 WST 2F112/WAVS aircrew readjustment. U.S. Navy message from FITRON ONE TWO FOUR to COMFITAEEWINGPAC, San Diego, CA.

This message discusses the sickness reaction of some trainees to the visual system of the F-14, WST, 2F112 simulator and notes that the effects were most prevalent on the trainee's first exposure to the visual system. Also noted was the wide variation in symptoms among individuals. The message suggests that after an initial training session, trainees not fly an actual aircraft for a minimum of 12 hours, and after subsequent training sessions, there should be a minimum of two hours before an actual flight. Furthermore, the simulator should only be started and stopped in a level position and that the white dome lights in the cockpit should be turned on before trainee exit.

Frank, L. H. (1981, August). Simulation sickness. Invited address, NASA Ames Research Center, Moffett Field, CA.

Simulator sickness incidence rates of approximately 10% in the F-14, 2F112 simulator and 48% in the E-2C, 2F110 simulator were documented in this presentation.

Frank, L. H. (1984). The role of visual-motion coupling in flight simulator sickness: a perspective. (Available from the author, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, VA).

The literature on visual-motion coupling in flight simulator design was reviewed. It was found that delays in the onset between the motion and visual subsystems of the simulator cause degraded pilot performance and is a suggested causal factor of simulator sickness. It was hypothesized that the current practice of temporally leading the onset of the visual subsystem with the motion subsystem may be antithetical.

Frank, L. H., and Crosby, T. N. (1982). Psychophysiological disturbances in the 2F117A, CH-46A WST (Memorandum N-712: LHF). Orlando, FL: Human Factors Lab, Naval Training Equipment Center.

The authors performed a preliminary investigation of the CH46A, 2F117A simulator and found that the horizon was not correctly displayed on a bank or turn, the display had noticeable flicker and the copilot could only see part of the display and that part was often out of focus. It was recommended that the simulator be further evaluated for training effectiveness.

Frank, L. H., Kellogg, R. S., Kennedy, R. S., and McCauley, M. E. (1983, April). Simulator aftereffects: sensorimotor disturbances induced in flight. In Proceedings of the Second Symposium on Aviation Psychology. (pp. 587-596). Columbus, OH: Department of Aviation, The Ohio State University.

If sickness occurs in the simulator, but not in the real world, there is evidence of a bad simulation. The authors reviewed the available data on simulator sickness in terms of their incidence, etiology, and contributing factors. It was found that psychophysiological disturbances can occur during simulator flight, continue several hours post-flight, or be delayed. Effects were found in both motion-base and fixed-base simulators, to pilots, other aircrew, and instructors. Simulator sickness may lead to decreased simulator use, distrust of the training received, and post-effects which may place the individual at risk in real-life situations such as driving a car. Adaptation, while it is known to occur, is not the answer. Adaptation to the simulator can lead to acquisition of responses which may produce negative transfer to the aircraft. Data on the relative incidence of simulator sickness in various trainers, its symptomatology, possible etiology, possible solutions and suggestions for research are discussed.

Frank, L. H., Kennedy, R. S., McCauley, M. E., Kellogg, R. S., (1983, June). Simulator sickness: Reaction to a transformed perceptual world--I. scope of the problem (Technical Note: NAVTRAEQUIPCEN TN-65). Orlando, FL: Naval Training Equipment Center.

If sickness occurs in the simulator, but not in the real world, there is evidence of a bad simulation. The authors reviewed the available data on simulator sickness in terms of their incidence, etiology, and contributing factors. It was found that psychophysiological disturbances can occur during simulator flight, continue several hours post-flight, or be delayed. Effects were found in both motion-base and fixed-base simulators, to pilots, other aircrew, and instructors. Simulator sickness may lead to decreased simulator use, distrust of the training received, and post-effects which may place the individual at risk in real-life situations such as driving a car. Adaptation, while it is known to occur, is not the answer. Adaptation to the simulator can lead to acquisition of responses which may produce negative transfer to the aircraft. Data on the relative incidence of simulator sickness in various trainers, its symptomatology, possible etiology, possible solutions and suggestions for research are discussed.

Hall, E. R., and Parker, J. F. (1967, June). A study of Air Force flight simulator programs (Tech. Report No. AMRL-TR-67-111). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratories.

This report concerned an Air Force high-performance tactical aircraft simulator used for IFR flight training (no visual scene). Regarding simulator sickness it was reported that the simulator motion system was not often used because it tended to induce nausea in student pilots and because it did not seem to be necessary from a training standpoint.

Hartman, B. O., and Hatsell, C. (1976, October). Field study: SAAC simulator. Brooks Air Force Base, TX: USAF School of Aerospace Medicine.

The symptoms reported by pilots training in the SAAC simulator are summarized. A discussion of simulator sickness etiology is also presented. The authors recommend the following: (a) give each new pilot at least one familiarization experience and avoid subsequent switching from motion-system-on to motion-system-off modes; (b) do not dampen the equations of motion governing the visual display; (c) upgrade the motion system to improve cue quality and reduce the tendency of the motion system to produce vertical periodic motions in the 0.2 Hz to 0.4 Hz range; (d) reduce the accommodation conflicts caused by the visual displays; and (e) synchronize the visual/motion systems.

Havron, M. D., and Butler, L. F. (1957, April). Evaluation of training effectiveness of the 2FH2 helicopter flight trainer research tool. (Tech. Report NAVTRADEVCE 1915-00-1). Port Washington, NY: Naval Training Device Center.

A six-hour training syllabus for the 2FH2 (simulator for the Bell HTL-4 helicopter) and a flight check consisting of common helicopter maneuvers were developed to evaluate the training capabilities of the 2FH2 engineering prototype. The training syllabus was administered to eighteen trainees (experimental subjects). The flight check was administered to these subjects and to eighteen comparable control subjects who had no training in the 2FH2. Major outcomes were: (a) experimental students performed no better than controls either on the flight check, or on training hit scores for training periods immediately following training in the 2FH2; (b) the 2FH2 gave approximately seventy-five percent of the instructors and students unpleasant sensations somewhat similar to motion sickness (a substantial number of subjects reported nausea, vomiting, blurred vision, and other intense and relatively persistent unpleasant sensations); (c) the 2FH2 gave the illusion of flying, however, subjects reported a number of serious lacks of fidelity of relationships between control movements and cockpit and extra-cockpit displays; and (d) factors in (c) above considered, it was doubtful that the 2FH2, as constituted at the time of this study, provided an adequate test of the concept of visual flight simulation. Therefore, there were ample reasons for the investigators not to recommend the 2FH2 for operational training.

Hendley, G. L. (1984, May). A listing of trainer visual systems. Paper prepared by Code 214, Orlando, FL: Naval Training Equipment Center.

This paper summarizes in tabular form the physical characteristics of the visual systems of 35 Navy flight and other simulators. Also provided is a brief nontechnical description of the characteristics of the visual systems typically used in flight simulators. A glossary of terms pertinent to visual systems is also included. The information in this report is useful in determining the features and types of known visual display systems which may influence the incidence of simulator sickness.

Jex, H. R., and Ringland, R. F. (1973, September). Notes on car simulator state of the art, motion, and visual requirements (Working Paper No. 2039-2). Hawthorne, CA: Systems Technology, Inc.

This paper presents: (a) uses and benefits of automobile driving simulators in design, research and training applications; (b) driving simulator subsystems (cab, interior, control, visual, auditory, motion and computer) and; (c) attributes that are particularly important to motion and visual simulation. The authors also propose that the reason some drivers feel discomfort in certain simulators is the presence of strong visually induced motion cues in the absence of corresponding physical cues. A chart of extant driving simulators and their features is provided, along with documentation of instances of simulator-induced discomfort.

Kellogg, R. S., Castore, C., and Coward, R. E. (1980). Psychophysical effects of training in a full vision simulator. In Preprints of the 1980 Aerospace Medical Association Meeting (pp. 203-215).

This paper presents the experiments designed to study the psychophysiological responses (dizziness, fatigue, nausea, motor imbalance and flash-back of visual experiences) to extensive training in the SAAC simulator. The results showed that a high proportion of experienced pilots exhibit some degree of simulator-induced sickness and/or mental fatigue. The authors note that the more trained the pilot, the more vulnerable he was to simulator sickness. It is suggested that: the pilot population be made aware of the possible occurrence of simulator-induced sickness, freezing of the display be reduced, the display not be turned on until the trainee is in the simulator, and that trainees be cautioned about possible post-flight reactions.

Kennedy, R. S. (1981, March). 2F87 (#5) aircraft operational flight trainer, trip report of sickness. U.S. Navy memorandum from CDR R. S. Kennedy to C.O., Naval Biodynamics Laboratory, New Orleans, LA.

This trip report discusses: (a) the sickness aircrew were experiencing in the P-3C, 2F87 simulator, (b) the installation of a baffle to block the flight engineer's view of the visual displays, and (c) the fact that trainees were experiencing postural disequilibrium with pilots reporting more ataxia than copilots. The author also observed that fewer aircrew were reporting sickness in the Canadian simulator (Aurora) than in the 2F87 and offered some possible explanations for this discrepancy.

Kennedy, R. S., Berbaum, K. S., and Frank, L. H., (1984). Visual distortion: the correlation model. (Tech. Paper 841595). Warrendale, PA: Society of Automobile Engineers.

Motion sickness is a disorder of the central nervous system, and it is believed to be due to sensory messages sent along input channels which either disagree with each other or with memory. The authors believe that to understand motion sickness one must understand how the stimulus is carried to the central nervous system and how it acts at the receptor level. It is the authors' view that motion sickness is a result of decorrelated sensory channels and this is in concert with the perceptual conflict theory. Within the perceptual conflict theory, correlations between sensory receptors build up over time. Decorrelation occurs when inputs are not in accord with what is expected from the neural store, or with the way in which that system is "hard-wired" to respond. This causes "trouble shooting" to begin. Troubleshooting may be analogous to the toxic reaction which develops when one is poisoned. Some people are more susceptible, perhaps analogous to being allergic, to toxic substances. Each sensory modality has channels and bandwidths of sensitivity. The conflict occurs when spatial (gain) and temporal (phase) aspects of the stimuli are not in accord. If the lack of accord occurs at places where the two channels are both sensitive, there is more disruption (poisoning) than at places where one or the other may be insensitive. Presumably, if discord occurs where both sensory modalities are insensitive, the stimuli are less toxic. It is possible that there may be conflicts between the two visual systems (focal and ambient) during perceived forward motion in a flight simulator.

Kennedy, R. S., Dutton, B., Ricard, G. L., and Frank, L. H. (1984). Simulator sickness: a survey of flight simulators for the Navy. (Tech. Paper 841597). Warrendale, PA: Society of Automotive Engineers,

Since World War II, the use of simulators for training has increased, due primarily to cost, maintenance, availability and safety. Orlansky and String (1977, 1979) have summarized simulator training effectiveness and cost effectiveness. Technologically advanced simulators, such as those for training air combat maneuvering, air cushion vehicles, and Skylab crews, are now commonplace. Unfortunately, there has been a recent increase in reports of discomfort and distress associated with the use of flight simulators. The data from a Navy sponsored survey of simulator sickness are described and a theoretical model is proposed in this paper.

Kennedy, R. S. and Frank, L. H. (1985). A review of motion sickness with special reference to simulator sickness. (Tech. Report NAVTRAEQUIPCEN 81-C-0105-16). Orlando, FL: Naval Training Equipment Center, Human Factors Division.

The authors reviewed relevant literature on motion sickness and developed an integrated (polysymptomatic and polygenic) theory to explain simulator sickness. A thorough discussion of perceptual conflict or sensory rearrangement theory is presented with specific emphasis on perceptual adaptation and decorrelation of receptors. This chapter provides a valuable theoretical background in motion sickness for the scientist or practitioner confronted with the simulator sickness problem.

Kennedy, R. S., Frank, L. H., McCauley, M. E., Bittner, A. C., Jr., Root, R. W., and Binks, T. A. (1984, April). Simulator sickness: Reaction to a transformed perceptual world--VI. preliminary site surveys. Paper presented at the AGARD Aerospace Medical Panel Symposium, Williamsburg, VA. and published in conference Proceedings No. 392.

There have been numerous, recent documented and anecdotal reports of aircrews experiencing psychophysiological disturbances, visual illusions and sickness following the use of flight simulators. Symptoms of simulator sickness occur not only during flight, but in some individuals, have lasted up to several hours post-exposure. Furthermore, simulator aftereffects may be delayed; some aircrews report symptom onset as late as eight to ten hours post-utilization. Incidents of simulator sickness have been documented in fighter, attack, patrol and helicopter simulators. These occurrences have been reported in both motion-base and fixed-base simulators, to pilots and other aircrewmen, as well as instructors. Preliminary data suggest that more experienced aircrewmen are at greater risk and that such factors as wide field-of-view and visual/inertial lag contribute to the problem. Simulator sickness represents a major obstacle to obtaining the full training potential from the vast inventory of flight simulators currently in use and under development. Obviously, the learning capability of an individual who is suffering discomfort generated by a simulator is greatly compromised. Moreover, there is the possibility that the visual and proprioceptive cues responsible for simulator sickness may contribute to negative transfer of training in actual flight. Data on pilot experience and exposure factors, symptomatology, scores on postural disequilibrium tests, video-game performance and engineering design aspects in two different Navy helicopter simulators are presented, along with a brief review of past simulator sickness studies.

Kennedy, R. S. and Graybeil, A. (1962). Validity of tests of canal sickness in predicting susceptibility to airsickness and seasickness. Aerospace Medicine, 33, 935-938.

Twenty-one subjects were exposed to a laboratory method for producing motion sickness (canal sickness) aboard the Slow Rotation Room. In an effort to determine the predictive ability of this method the subjects were also subjected to aerobatics in an aircraft and to heavy or calm sea states. In addition nystagmic response to caloric stimulation was observed. It was found that a positive relationship existed between performance on the Slow Rotation Room, caloric irrigation, and airsickness. This relationship also existed during heavy seas and to a lesser extent in moderate seas. Such tests may also exhibit predictive sensitivity for simulator sickness susceptibility.

Leibowitz, H. W., Shupert, C. L., and Post, R. B. (1983, April). The two modes of visual processing: Implications for spatial orientation. Paper presented at the Peripheral Vision Horizon Display Conference, Edwards Air Force Base, CA.

The authors discuss the concept of the existence of two modes of visual systems (focal and ambient), how these systems differ, and how a mismatch between the two can be a cause of disorientation and motion sickness.

Lilienthal, M. G., (1986, January) Simulator Sickness in Flight Simulations: A Case Study. Paper presented at the Transportation Research Board Meeting, Washington, D.C. (In press for the Transportation Research Record.)

Simulator sickness is a recently publicized phenomenon in which pilots who use flight simulators experience symptoms characteristic of motion sickness. This report presents a field study performed on a Navy helicopter simulator (Device 2F-12) to identify and correct factors suspected of causing simulator sickness. A sample of 42 United States marine aviators, before and after training in the simulator, revealed a significant incidence of simulator sickness. Symptom clusters most often reported included general discomfort, headache, nausea, and fullness of the stomach. Observational data point to the visual system as the primary cause of this particular system. Changes in procedures and equipment for the visual system are recommended.

Matheny, W. G., Dougherty, D. J., Willis, J. M. (1963). Relative motion of elements in instrument displays. Aerospace Medicine, 34, 1041-1046.

The authors present two experiments: the first demonstrated that motion is a relevant variable in the evaluation of displays when motion cues are normally present; the second experiment demonstrated that in certain systems the operator receives information from the kinesthetic sense before information is received from the visual sense, and this experiment suggests the importance of motion fidelity. Taken together the results from these experiments suggested not only that motion is a relevant variable, but that the degree to which it duplicates the angular motions of the vehicle being simulated is most important. Lack of the motion cues may lead to erroneous conclusions as to the suitability of displays for systems in which motion cues are present. Motion simulation systems, which exhibit transient accelerations or unrealistic phase differences between motion and visual stimuli, may provide cues to responses which are inappropriate to the task of the operator. Such faults in motion simulation may be equally serious for those situations in which the simulator is used as a training device as for those in which it is used as a design and evaluation tool. Furthermore, the faults may contribute to the production of sickness in operators of the simulator.

McCauley, M. E. (Ed.). (1984). Research issues in simulator sickness: proceedings of a workshop. Washington, D.C.: Committee on Human Factors, National Research Council, National Academy Press.

Simulator sickness, with symptoms similar to motion sickness, occurs frequently in military and civilian flight trainers. This report presents an overview of the deliberations of the 1983 National Research Council Workshop on Simulator Sickness. Topics included in the report are simulator characteristics, theories of motion sickness and adaptation, recommended countermeasures against simulator sickness, research needs, and a listing of a variety of potential contributors to simulator sickness.

Note: Several attendees listed in this report provided "position" papers on simulator sickness for distribution at the workshop. These papers may be requested from the individual authors.

McGuinness, J., Bouwman, J. H., and Forbes, J. M. (1981). Simulator sickness occurrences in the 2E6 air combat maneuvering simulator (ACMS) (Tech. report NAVTRAEQUIPCEN 80-C-0135-4500-1). Orlando, FL: Naval Training Equipment Center.

In March 1980, it was reported that a few Navy personnel were experiencing some disorientation or discomfort while flying the Air Combat Maneuvering Simulator (ACMS-designated Device 2E6). Recognizing the need for pursuing this matter further, a study was initiated to determine the extent of the problem. This report describes the methods and results of a preliminary study undertaken to assess the rate of occurrence and the degree of severity of "simulator sickness" experienced by individuals who have "flown" the Device 2E6, Air Combat Maneuvering Simulator. Twenty-seven percent of the aircrews from F-4 and F-14 squadrons at NAS, Oceana, Virginia Beach, Virginia experienced varying symptoms during and/or after use of this simulator. Sixty-one percent of those experiencing symptoms reported persistence of the symptoms from fifteen minutes to six hours after a simulator session ended. At the time of the study, this was a new simulator installed in November 1979, therefore, the period of observation was limited. Further investigation of simulator sickness was planned when a structured curriculum was to be incorporated into the training program and modifications were to be made to the simulator.

McLane, R. C. and Wierwille, W. W. (1975). The influence of motion and audio cues on driver performance in an automobile simulator. Human Factors, 17, 488-501.

A highway driving simulator with a computer-generated visual display, physical motion cues of roll, yaw, and lateral translation, and velocity-dependent sound/vibration cues was used to investigate the influence of these cues on driver performance.

Forty-eight student subjects were randomly allocated to six experimental groups. Each group of eight subjects experienced a unique combination of the motion and audio cues. The control group received a full simulation condition while each of the remaining five groups performed with certain combinations of motion and sound deleted. Each driver generated nine minutes of continuous data from which five performance measures were derived. Results indicate that the performance measures of yaw, lateral, and velocity deviation are significantly affected by the deletion of cues. In support of the hypothesis that driver performance is augmented by the addition of motion cues, statistically significant negative correlations were obtained between the number of motion cues present and the measures of yaw and lateral deviation. With respect to motion and audio cues, recommendations are made regarding simulator design criteria.

Miller, J. W. and Goodson, J. E. (1958, February). A note concerning "motion sickness" in the 2FH2 hover trainer (Report No. 1, Project NM 17 01 11, Subtask 3). Pensacola, FL: Naval School of Aviation Medicine. Bureau of Medicine and Surgery.

A review was made of the development of simulator 2FH2, for the Bell HTL-4 helicopter including two evaluations. These evaluations pointed with no little concern to the problem of "motion sickness" experienced in the simulator. The writers felt that the hypotheses offered by others to the effect that these symptoms were elicited by the conflict between visual cues of motion and static physiological cues was false. The problem seemed to lie in one or a combination of several modes of distortion: there existed both static and dynamic distortions in the projected scenery; there were errors in the perceived directional changes of motion; and there are dynamic errors in the perceived angular rate of motion. These distortions were pointed out and suggestions made as to how they might have been alleviated.

Miller, J. W. and Goodson, J. E. (1960). Motion sickness in a helicopter simulator. Aerospace Medicine, 31, 204-212.

Simulation of operational aircraft has become an increasingly important aspect of flight training for reasons of economy, safety, expediency. In 1956 a helicopter simulator, device 2FH2 was designed and installed as a training device in Pensacola, Florida, for the dual purpose of evaluating a point source system of optical projection and as a possible means of facilitating the training of helicopter pilots. During the initial stages of utilization a number of problems arose concerning the desirability of employing this device as a training instrument. One of the most serious difficulties encountered was that of so called "motion sickness" in a cockpit that did not actually move. The problem became so serious that it was one of the chief reasons for discontinuing the use of the simulator. This paper discusses a number of simulator design characteristics which potentially influenced the incidence of pilot sickness.

Money, K. E. (1980). Flight simulator motion sickness in the Aurora CP 140 FDS (DCIEM Tech. Communication 80-C-44). Downsview, Ontario: Defence and Civil Institute of Environmental Medicine.

This paper discusses the magnitude, probable causes and the experiences of simulator users concerning simulator sickness. The author suggests twelve procedures that may reduce sickness such as: keep to a minimum the amount of turbulence in flight, use freeze mode and resetting mode as little as possible, use of antinotion sickness drugs and, as a last resort, turning off the motion base.

Parker, D. M. (1964). An investigation of autonomic function in motion sickness and revulsion. Unpublished doctoral dissertation, University of California at Los Angeles.

Autonomically mediated responses of male subjects were studied during the presentation of three motion pictures in order to determine if significantly different patterns of response could be elicited, and to investigate causal factors in motion sickness. One film of motion was produced to elicit motion sickness, one of a surgical operation was selected to elicit revulsion, and the third presentation was merely the motion film run backwards. The three groups were compared on the basis of maximum changes of the variables as measured from prestimulus control film means. Significant differences were found between the surgical and motion film groups in terms of the following variables:

Variable	Motion	Surgical
Volar skin conductance	increase	less increase
Face temperature	increase	decrease
Finger pulse volume	decrease	increase
Respiration rate	decrease	less decrease
Heart rate	increase	decrease

Little response was shown to the motion reversed film, and comparison of the responses of this group with those of the surgical and motion groups shows many significant differences, some of which can be clearly recognized as components of pattern differences. Motion sickness symptoms appeared in all motion group subjects, although there was no form of vestibular stimulation employed. It was concluded that: (1) There are clear cut differences in the patterns of autonomically mediated responses to films designed to elicit motion sickness and revulsion. (2) Vestibular stimulation is not a necessary condition for the production of symptoms of motion sickness. (3) Motion sickness is not necessarily a result of cue disparity. Other findings suggest that susceptibility to motion sickness as produced in the present study is related positively to scores of autonomic function indicating apparent parasympathetic dominance, and that a visceral action theory of emotion is supported.

Parker, D. M. (1971). A psychophysiological test for motion sickness susceptibility. Journal of General Psychology, 85, 87-92.

Skin conductance measures were taken from the volar forearm surface of 92 male and female subjects while they were watching a film of a high speed automobile ride down twisting mountain roads. Subjects who showed a change of at least .100 micromhos were judged to be motion-sickness prone. Ten susceptibles and 10 nonsusceptibles were taken to sea on a sailing vessel. All of the predicted susceptibles showed vomiting or reported severe nausea; none of the nonsusceptibles showed any symptom. These findings were related to Reason's 'receptivity' hypothesis. A modification of the hypothesis was advanced proposing that not only was receptivity related to susceptibility, but that the central nervous system processing of those stimuli into meaningful perceptions was critical. The validity of the volar conductance measure was perfect with subjects who lacked experience with the sea. It was questioned whether the test had wide general validity among well practiced subjects, or whether it would predict susceptibility to other forms of motion sickness. It was concluded that the volar sweating test promised more accurate assessment of motion sickness susceptibility than measures heretofore employed, and that Reason's hypothesis might be modified to include central nervous system information processing as a critical variable.

Puig, J. A. (1970). Motion in flight training: a human factors view (Tech. Report NAVTRADEVCEH IH-177). Orlando, FL: Naval Training Device Center.

An in-house study was conducted to review the status of simulation technology as applied to training, with emphasis on human factors problems encountered in visual and motion simulation. The effects of incorporating motion in ground-based visual simulators was considered with respect to its influence on training and its role on a possible inhibitor of simulator sickness. The position of the Human Factors Laboratory was expressed on several aspects of simulation related to training technology. A large portion of the report addresses simulator sickness, noting 10 hypothesis as to its etiology and a number of design and research issues.

Puig, J. A. (1971, November) The sensory interaction of visual and motion cues. In Commemorative Technical Journal, NTDC 25th Anniversary. Orlando, FL: Naval Training Device Center.

Effective training design requires that the significance of cue interactions be established. Care must be taken to incorporate into the training device not only the cues required for training specific tasks, but the essential combinations of cues as well. This paper discusses visual and motion interaction from the standpoint of: (a) illusions and spatial disorientation; (b) spatial orientation training; and (c) simulator sickness.

Reason, J. T., and Brand, J. J. (1975). Motion sickness. New York: Academic Press.

The authors present the history, symptoms, theories and discuss the extent of motion sickness. An explanation of the physiology of the vestibular system and its role in motion sickness as well as salient features of the etiological stimuli, adaptation to the stimuli, individual differences in susceptibility and preventive measures that can be taken to lessen the effects of motion sickness is also presented. The authors propose the "sensory rearrangement" theory and discuss it in light of other theories concerning the cause of motion sickness.

Reason, J. T. and Diaz, E. (1971, July). Simulator sickness in passive observers. (Report NO. FPRC/1310; AD 753560). London: Flying Personnel Research Committee, Ministry of Defense.

Fifteen women and sixteen men were given a 10-minute "ride" in a fixed-base car simulator with a moving visual display (Sim-L-Car). These exposures were standardized, and included a considerable amount of implied (but not actual) vestibular stimulation. Approximately one-half of the subjects wore "blinkers" which restricted their field of view to the dynamic visual display. The principal findings were: (a) some measurable decline in well-being was reported by 28 of the 31 subjects; (b) women were significantly more susceptible than men; (c) both previous passenger and car driving experience correlated positively with the degree of disturbance produced by the simulator, but driving experience appeared to exert the greatest influence upon susceptibility; and (d) exclusion of the static features of the field of view appeared to have no effect upon susceptibility. These results were interpreted in the light of the "sensory rearrangement" theory of motion sickness.

Ryan, L. E., Scott, P. G., and Browning, R. F. (1978, September). The effects of simulator landing practice and the contribution of motion simulation to P-3 pilot training (TAEG Report No. 63). Orlando, FL: Naval Training Analysis and Evaluation Group.

In reference to simulator sickness, this report indicates that exposure to a P-3 simulator, device 2F87, produced symptoms of tiredness and drowsiness, which may be attributable to prolonged simulator sessions, time of day, or simulator-induced discomfort. Some trainees reported headache and mild unsteadiness. No-motion groups reported their simulator flights of 4-hour duration as less physiologically disturbing than comparison groups undergoing a 10-minute exposure to a brief vestibular disorientation test or a 6-minute exposure to a visual-vestibular interaction test. Both students and instructors seemed to prefer having motion cues available in the simulator.

Sinacori, J. B. (1967, November). V/STOL ground-based simulation techniques (USAAVLABS Tech. Report 67-55). Fort Eustis, VA: U.S. Army Aviation Material Laboratories (Prepared by Northrop Corporation, Norair Division, Hawthorne, CA).

A study of various kinds of simulators has been made to determine their capability to produce data representative of visual flight. Four simulations of a jet-lift V/STOL aircraft were conducted using the same pilot. Control characteristics and airframe parameters were maintained constant (as closely as possible), and the same tasks were used by the pilot in each evaluation. The resulting data were compared with flight results from the same aircraft. The simulators used different displays, motion modes, and instrumentation, and the results are discussed in the light of the characteristics of each simulator. The results show clearly that in order to produce quantitative data representative of flight results, the display must have a quality level compatible with the task being performed. Specifically, a precision hovering task required a high resolution display, while a translation (or transition task) can be performed with a display of much less resolution. The display content is important, particularly for the precision hovering task where height holding is required. For flight simulation of large translational movements, cockpit motion did not appear to affect the results, however, for precision hover and small, quick position changes, cockpit motion appears to be important in that it assists the pilot in detecting small drift and improves his ability to control vehicle attitude. The absence of cockpit motion when using a point source visual display for the presentation of visual information can cause vertigo and loss of performance. The study shows that valid V/STOL flight simulation can be accomplished and that quantitative and subjective data which closely compare with flight results can be obtained.

Sinacori, J. B. (1983, September). Coping with simulator sickness -- an engineer's view. Position paper prepared for the National Research Council Workshop on Simulator Sickness, Monterey, CA.

This paper presents a review of the sickness problems which accompanied development of a V/STOL simulator, and how they were ameliorated through addition of motion cuing and subsequent tuning of washout algorithms. Some insights, however, are offered as to the simulation features that may influence simulator sickness. A list of these features follows: 1) Visual display field-of-view size and shape; 2) Visual scene content, i.e. the total number of differentiated patch boundaries contained in the visible solid angle and their distribution--this is not necessarily an indicator of scene information value; 3) The spectrum of the visual movements; 4) The spectrum of the difference between the visual movements and those transmitted to the human through the other sensors, e.g. the vestibular system. The effects of hardware delays, lags and drive laws are described by this also.

Smode, A. F. (1971). Human factors inputs to the training device design process. (Tech. Report NAVTRADEVCEEN 69-C-0298-1). Orlando, FL: Naval Training Device Center.

This report presents guidelines for achieving human factors inputs to the design of synthetic training systems. It provides a method for design and organized training concepts and data supportive to the human factors specialist in deriving the functional specifications for the design of any complex training device. Three major sections are provided. The first of these presents an organized method for achieving human factors inputs to training system design. Another section presents concepts and data applicable to the design of training devices. Seven content chapters are subsumed under this section. These are: (a) visual simulation, (b) platform motion simulation, (c) vehicle control requirements, (d) information processing requirements, (e) measurement system design, (f) adaptive training strategies, and (g) deliberate departures from realism in design. For each chapter, concepts and data which provide human factors design support are articulated based on a review of the pertinent literature. Where design evidence is meager, the data gaps are identified. Research issues of high priority for human factors design were recommended. The final section provides a demonstration of the human factors design process for a complex training system. Many of the issues raised have direct bearing on the design of training devices to avoid simulator sickness.

Staples, K. J. (1978, January) Current problems of flight simulators for research. Aeronautical Journal, pp. 12-32.

Characteristics of the three main systems of simulators (computer systems, visual systems, and motion systems) and other hardware and software elements that contribute to the quality of simulation are presented and discussed.

Testa, C. (1969). The prediction and evaluation of simulator illness symptomatology. Unpublished doctoral dissertation, The University of California at Los Angeles.

The purpose of the research was to explore the illness experienced by many subjects in a driving simulator. Two major hypotheses were investigated. The first hypothesis stated that the disparity in incidence of illness could be attributed to differences in perception between extremely field independent (EFI) and extremely field dependent (EFD) individuals. The second hypothesis was formed to test the effect of suggestion or motivation upon simulator illness. The four measures of illness used in the study included perspiration, respiration, galvanic skin responses and questionnaire scores. The two groups of subjects (EFI and EFD) react differently to suggestion. The EFD subjects given a positive set of instructions experienced more illness than those given a null set. On the other hand, the EFI subjects given a positive set of instructions experienced less illness than those given a null set. There was an apparent threshold value near the boundary of the EFI classification above which subjects become ill and below which they were able to tolerate the simulator. It was concluded that both objective and subjective symptoms were required to properly identify and evaluate simulator illness.

Wenger, J. E. (1980). Motion sickness in the P-3C fleet readiness trainer at Naval Air Station, Brunswick, ME. (memorandum NBDL:60:jah;6500). U.S. Navy memorandum from C.O., Naval Biodynamics Laboratory to Commander, Naval Air Systems Command, Washington, D.C.

This summary of the investigation of sickness resulting from use of the P-3C simulator explores two phenomena - first only the flight engineers and not the pilots or copilots experienced sickness; secondly, symptoms in a similar simulator were not producing any appreciable symptoms. The authors felt the main cause was the flight engineer's off-axis and therefore, distorted view of the display. It was suggested that the flight engineer's view be blocked, head movement minimized and the motion system be secured when training a flight engineer with minimal flight time. The author also notes that the motion system lags the visual system and that depth cues presented in the display were conflicting.

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